



Buffalo Ditch Total Maximum Daily Load Withdrawal

Public Notice
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1. Introduction

On March 3, 2010, the U.S. Environmental Protection Agency (EPA), Region 7 approved a total maximum daily load (TMDL) for Buffalo Ditch (Water Body ID 3118). The TMDL was developed by the Missouri Department of Natural Resources with modeling support provided by EPA and its contractor, Tetra Tech. The TMDL was developed to comply with the requirements and schedules of the 2001 consent decree, *American Canoe Association, et al. v. EPA*, Consolidated Case No. 98-1195-CV-W-SOW, consolidated with 98-4282-CV-W-SOW. The purpose of the TMDL is to address a protection of warm water aquatic life designated use impairment resulting from low dissolved oxygen concentrations in Buffalo Ditch. Dissolved oxygen (DO) is measured as the concentration of oxygen molecules dissolved in water that is readily available for chemical and biological processes. To restore DO concentrations in the water body, the TMDL provides loading targets for total nitrogen (TN), total phosphorus (TP), total suspended solids (TSS), and, for the city of Kennett wastewater treatment plant (WWTP), biochemical oxygen demand (BOD). The TMDL assigns specific wasteload allocations to the Kennett WWTP and municipal separate storm sewer system (MS4) and aggregated wasteload and load allocations to other point and nonpoint sources to achieve the TMDL targets. An implicit margin of safety was incorporated into the TMDL based on conservative assumptions applied to the models.

At the request of the city of Kennett, the Department reviewed the Buffalo Ditch TMDL administrative record and determined technical issues exist with the underlying assumptions and inputs in the models used to calculate loading targets. The Department further determined even if rectified and fully implemented, the reductions called for in the TMDL would not result in attainment of the existing minimum DO criterion of 5.0 mg/L. This conclusion is based upon an evaluation of the water quality models used and empirical evidence of naturally occurring low DO conditions in Buffalo Ditch and other streams within the Bootheel region of southeast Missouri. Specifically, technical issues identified by the Department include the following:

- The QUAL2K (Q2K) model was developed using flows that are not representative of critical low flow conditions in Buffalo Ditch and result in flawed hydraulic geometry relations;
- The Q2K model uses an inappropriate formula for low-gradient channelized streams to predict reaeration rates along the segment;
- The Q2K model assumes sediment oxygen demand (SOD) rates that are not representative of streams in the Bootheel and are not supported by data or literature; and
- The synthetic flow record developed to construct load duration curves for Buffalo Ditch included inappropriate gage data showing low statistical accuracy and are unrepresentative of Bootheel stream conditions.

Title 40 of the Code of Federal Regulations (CFR) at §130.7(c)(1) requires TMDLs to be developed to meet applicable water quality standards. Even if the previously mentioned modeling issues are resolved, the water quality model indicates implementation of the TMDL through point source pollutant reductions alone will not lead to attainment of Missouri's minimum DO criterion in Buffalo Ditch. The unique history of stream modification in the Bootheel and existing physical conditions throughout the region are additional factors that reduce DO and generally preclude consistent attainment of the DO criterion across the region.

Due to issues identified in the TMDL models, the Department proposes to withdraw the Buffalo Ditch TMDL and re-categorize the Buffalo Ditch DO impairment as Category 5 for inclusion on the Missouri 303(d) list of impaired waters. Waters included on the 303(d) list will be prioritized and scheduled for TMDL development as required by 40 CFR §130.7(b)(4). Implementation actions and other planning efforts in the Buffalo Ditch watershed that are more immediately beneficial or practicable for achieving water quality standards than a revised TMDL may result in further subcategorization of this impairment as Category 5-alt. Category 5-alt waters remain on the 303(d) list, but are considered low priority for TMDL development because actions and efforts in the watershed will lead to attainment of water quality standards more rapidly than the TMDL process. Actions in the Buffalo Ditch watershed that may serve as alternative restoration approaches more immediately than a revised TMDL are described in more detail in Appendix A.

2. Background

Buffalo Ditch originates on the northeast side of Kennett, Missouri and flows south-southwest into the state of Arkansas (Figure 1). It is located in Dunklin County within the low-lying Bootheel region of southeastern Missouri within the Little River Ditches watershed (8-digit Hydrologic Unit Code 08020204) and is part of the Little River Drainage District. The Little River Drainage District was formed in 1907 with the goal of opening the region for settlement and agricultural production. In the early 20th century, the Little River Drainage District administered the construction of a system of ditches, levees, and canals throughout the Bootheel region (LRDD 2018). These drainage ditches and canals converted wetlands that previously dominated the region into cropland that supports soybean, corn, grain sorghum, cotton, and rice farming. Today, land use within the Buffalo Ditch watershed consists of 91 percent cropland (MoDNR 2010).

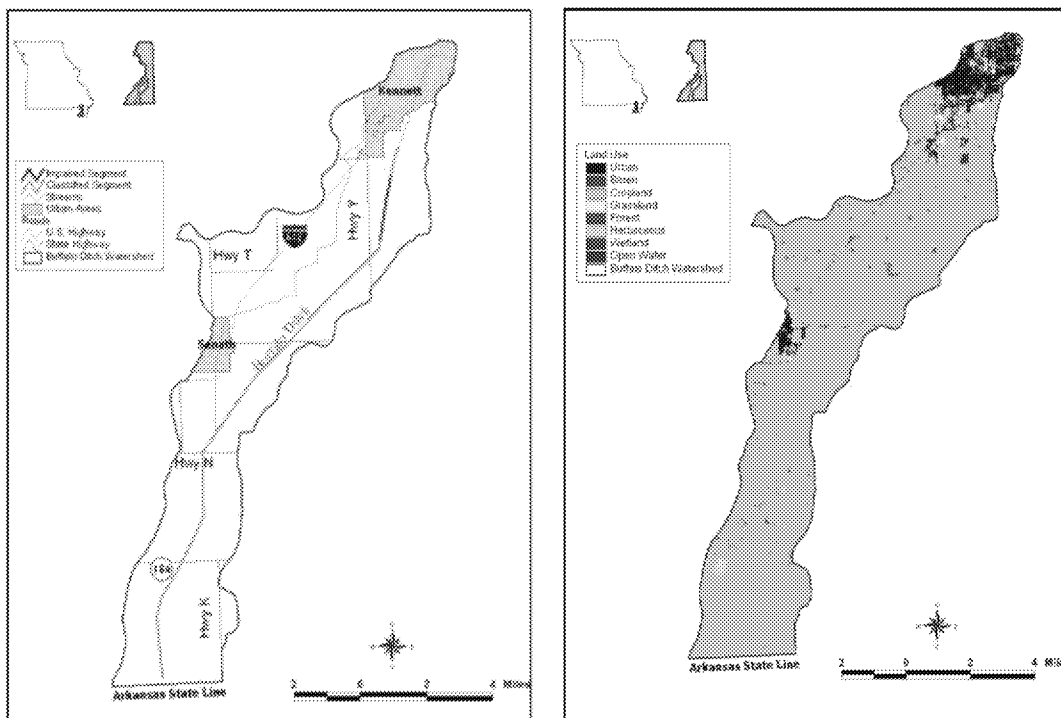


Figure 1. Buffalo Ditch Watershed and Associated Land Uses (MoDNR 2010)

2.1 Buffalo Ditch Dissolved Oxygen Impairment History

Buffalo Ditch was initially included on Missouri's 1994 Section 303(d) List of impaired waters for BOD concentrations not meeting protection of the warm water aquatic life designated use. BOD refers to the amount of oxygen consumed by microorganisms during break down of organic matter and is used as a surrogate for the degree of oxygen consuming organic matter in water. There are no water quality criteria for BOD, but it is frequently linked to DO which has a minimum allowable criterion of 5.0 mg/L (10 CSR 20-7.031 Table A1) for all Missouri streams except streams designated as cold water aquatic habitats. To provide a more understandable 303(d) list to the general public, the pollutant was changed from BOD to DO on the consolidated 2004/2006 303(d) List. This change was maintained on the 2008 303(d) List from which the Buffalo Ditch TMDL was developed.

2.2 Regional Factors that Contribute to Low Dissolved Oxygen

The unique history of waterways in the Bootheel and existing physical conditions throughout the region, are known to reduce ambient DO and generally preclude consistent attainment of the DO criterion across the region. As noted previously, the Bootheel region historically supported an extensive network of wetlands. Natural wetlands in the region are generally characterized by physical properties that are likely to contribute to low DO conditions, such as being shallow, highly productive, and having little gradient. The construction of ditches, levees, and canals throughout the region further exacerbate these issues, preventing the DO criterion from being widely attained.

A summary of DO data collection efforts for streams in the Bootheel compiled during development of the Buffalo Ditch TMDL, as well as potential regulatory alternatives for addressing the unique physical conditions of Bootheel streams, is presented in Appendix B. Physical conditions that contribute to low DO concentrations in the Bootheel, and specifically to Buffalo Ditch (Figure 2), include lack of stream riparian cover and low stream gradient.

Riparian Cover

Trees, shrubs, and other vegetation that grow alongside a stream (the riparian corridor) have a strong influence on instream water quality. Wooded riparian buffers are a vital functional component of stream ecosystems and are instrumental in the detention, removal, and assimilation of pollutants in runoff. The shading effects of a good riparian corridor keep temperatures along and in the stream cooler than the surrounding landscape. As wetlands were drained in the Bootheel region, vegetation was also removed from the landscape and along water bodies. Approximately 85 percent of the riparian corridor along Buffalo Ditch is cropland and another 10 percent is urban (MoDNR 2010). The loss of vegetative cover in these areas results in less shading and higher instream temperatures. Increased water temperature lowers the DO saturation capacity of streams and accelerates chemical and biological oxygen-consuming processes, resulting in lower DO levels. One way to reverse the impact of higher stream temperatures on DO is to replant and restore riparian corridors. However, this action may not be feasible in the Bootheel region where the riparian corridors of many streams and ditches must be kept clear of vegetative cover to ensure dredging and other operation and maintenance activities conducted by local drainage districts are accomplished.

Stream Gradient

The difference in elevation between the headwater and outlet of a stream segment, divided by the stream segment length, is the stream's gradient. A stream's gradient, along with flow and bottom characteristics, plays an important role in determining the amount of oxygen that can be dissolved in the water body. A shallow, high gradient stream has the potential for more turbulent flow than a shallow, low gradient stream. Increased turbulence in a stream promotes reaeration of the water body and higher instream DO concentrations. Streams having a low-gradient (less than 1 percent slope) experience lower reaeration rates due to a reduction in average flow velocity and are more susceptible to low DO conditions. Buffalo Ditch is situated in the low-lying Bootheel region, which is a relatively flat alluvial plain with extremely low gradients. Slopes estimated by EPA for the Buffalo Ditch TMDL range from approximately 0.0002 to 0.0005 percent. Average channel gradients in the Bootheel region (Mississippi Alluvial Basin) are 2.6 meters per kilometer (m/km) for headwaters and <1 m/km for other streams, which are substantially lower than gradients in the Central Plains (10.3 m/km for headwater streams, 2.3 m/km for creeks, and 0.7 m/km for small rivers) and the Ozarks (17.4 m/km for headwaters, 4 m/km for creeks, and 1.2 m/km for rivers) (Sowa et al., 2005). Because stream gradient plays a central role in determining reaeration and other kinetics related to DO, ensuring that appropriate values and reaeration equations are used is an extremely important consideration.

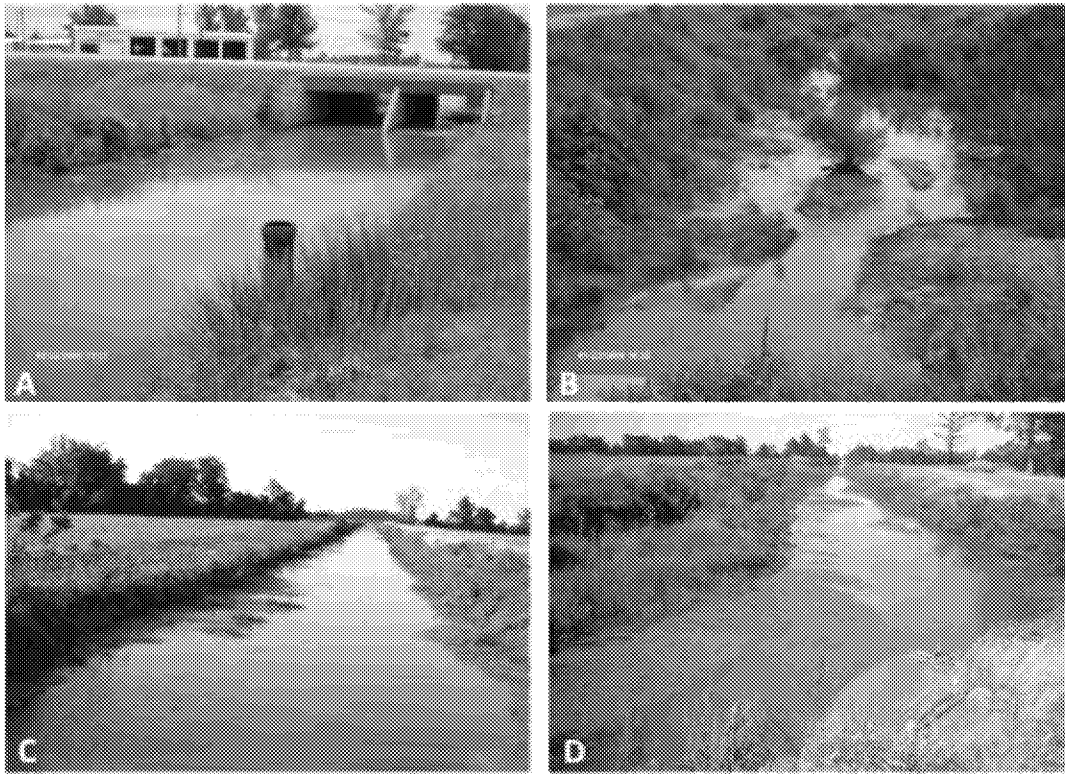


Figure 2. Buffalo Ditch sampling sites BU-1 (A) and BU-2 (B) upstream of Kennett WWTP and sites BU-4 (C) and BU-5 (D) downstream of the facility during May 2008 sampling event.

3. Review of the Buffalo Ditch TMDL

The Department has reviewed the Buffalo Ditch TMDL and underlying water quality models used for establishing wasteload and load allocations. A number of technical issues that impact model predictions have been identified. Given these issues, the Department has determined the TMDL models are not representative of low flow stream conditions in Buffalo Ditch and implementation of the TMDL will not result in the attainment of the applicable minimum 5.0 mg/L DO criterion. These issues and their impact on Buffalo Ditch water quality predictions are described in greater detail in the following subsections.

3.1 TMDL Summary

The Buffalo Ditch TMDL established loading targets for TN, TP, and TSS. The TMDL allocated specific pollutant loads to the Kennett WWTP and MS4, while assigning aggregated loads to nonpoint sources and other permitted point sources in the watershed. An additional wasteload allocation for BOD was determined for the Kennett WWTP (Table 1). Ecoregional concentration targets were used to establish nutrient and sediment loading allocations for point and nonpoint sources using load duration curves. The EPA-supported water quality model Q2K was utilized to derive a BOD wasteload allocation for the Kennett WWTP, which the model predicted would achieve the 5.0 mg/L minimum DO criterion. During critical, low flow conditions, nonpoint sources and the Kennett MS4 are not expected to contribute pollutant loading to Buffalo Ditch.

Table 1. Buffalo Ditch TMDL allocations at critical low flow conditions.

Pollutant	Concentration Targets	Wasteload Allocation			Load Allocation
		Kennett WWTP (at Design flow = 2.17 cfs)	Kennett MS4	Other permits	
Total Nitrogen	0.76 mg/L	8.9 lbs/day	0	1.61 lbs/day	0
Total Phosphorus	0.115 mg/L	1.35 lbs/day	0	0.24 lbs/day	0
Total Suspended Solids	31 mg/L	362.9 lbs/day	0	65.56 lbs/day	0
BOD	5.0 mg/L	58.5 lbs/day	0	NA	NA

Tetra Tech, under contract with EPA, planned to sample Buffalo Ditch and a paired reference stream at moderate flow conditions during the spring or summer and at low flow conditions during the summer of 2008. A three-day diel DO study above and below the WWTP outfall and on the reference stream was also planned during the low flow sample collection. The sites sampled in May and September 2008 are identified in Figure 3. Sample locations consist of two sites above and three sites below the Kennett WWTP discharge, with the furthest downstream beyond the extent of the impairment. An additional sampling site was located on a paired reference stream. All data were collected in accordance with required quality assurance procedures and Department sampling protocols (Tetra Tech, 2008a; Tetra Tech, 2008b; MDNR, 2005).

Tetra Tech deployed data loggers (sondes) during the May 2008 sampling event when Buffalo Ditch was experiencing moderate flow conditions. The sondes monitored 15-minute temperature and DO concentrations at three sampling locations (BU-2, BU-4, and BU-Ref) for three days. During this time, Tetra Tech field staff conducted cross-sectional measurements at each sampling location, except for the WWTP outfall (at BU-3). Water temperature, conductivity, specific conductance, pH, and DO were collected *in-situ* from each site and grab samples were collected for lab analysis of chlorophyll *a* (chl-*a*), 5-day carbonaceous BOD, dissolved organic carbon, ammonia nitrogen, nitrate/nitrite nitrogen, TP, total organic carbon, TSS, and volatile suspended solids.

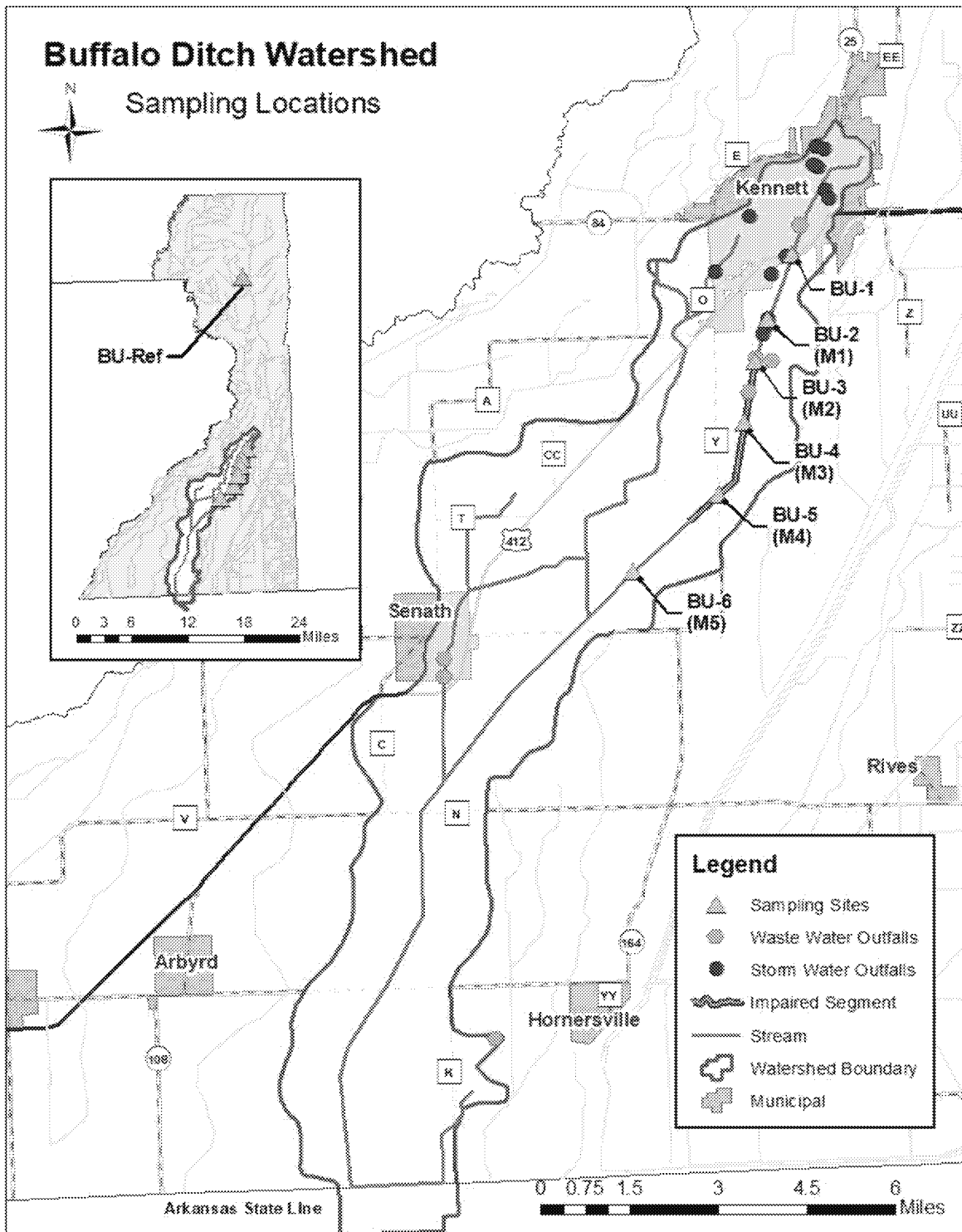


Figure 3. Buffalo Ditch TMDL sampling sites

Diel DO monitoring of low flow conditions did not occur during the September 2008 sampling event. According to the Buffalo Ditch TMDL, Tetra Tech did not monitor three day DO fluxes due to “high flows associated with the aftermath of Hurricane Ike” which precluded the deployment of the data loggers. However, Tetra Tech did manage to collect grab samples and transect measurements at this time. Field sheets note that measurements and samples were not collected from site BU-2 due to no flow. This documented contradiction regarding flow conditions at the time of the September 2008 sampling event creates uncertainty with respect to the data used for TMDL development.

The Buffalo Ditch TMDL provides an overview of the data collected during the May and September 2008 sampling events. It was noted in the TDML that the May 2008 data reveals a relationship between elevated TP and nitrate + nitrite concentrations of the WWTP effluent and the following few miles downstream. Samples collected in September 2008 show slightly less TP concentrations, but extremely decreased nitrate + nitrite effluent concentrations, which were correspondingly reflected in the downstream water quality. The TMDL also remarks that chl-a concentrations were high at site BU-6 and above the WWTP outfall in May and September. These data suggest that high nutrient loads above and below the outfall are contributing to excessive algal growths indicating a need for additional nonpoint source reductions than the models indicate.

3.2 The QUAL2K Model

EPA selected the Q2K model to support an analysis of the assimilative capacity of Buffalo Ditch for oxygen-demanding processes. Q2K is a one-dimensional model that assumes a vertically and laterally well-mixed water body and simulates basic stream water movement and water quality processes. The TMDL water quality model addresses nutrient cycles, algal growth (photosynthesis and respiration), and DO dynamics, such as BOD, SOD, and atmospheric reaeration. SOD is the oxygen consumption due to decaying organic matter in the sediments of a water body. Atmospheric reaeration represents the addition of oxygen to the water body from the atmosphere.

The process of developing a Q2K model, such as that applied to Buffalo Ditch, contains the following steps: 1) define the stream geometry based on *in situ* measurements; 2) assign flow and water quality inputs for the headwater boundary, model reaches, and point and nonpoint sources; and 3) complete model calibration and validation analyses. Model calibration refers to the process of adjusting various model rates and parameters to within acceptable ranges as defined by literature and standard modeling practice so modeled processes best match field data. Model validation is an extension of the calibration process and refers to testing the calibrated model predictions against a separate, independent dataset. Once an acceptable level of calibration and validation has been achieved, the model is considered useful for predicting water quality changes associated with management actions. In this projection mode, the water quality model becomes a critical component of the TMDL process for determining the loading capacity of a water body. The calibrated and validated water quality model demonstrates the necessary linkage to establish the cause-and-effect relationship between the numeric targets and the pollutant sources (EPA 2002).

The Final Quality Assurance Project Plan (QAPP) for Data Collection for Missouri DO TMDLs identifies the water quality parameters required to support the Q2K water quality model (Tetra Tech, 2008a). The QAPP specifically outlines the need for data collected during two separate flow regimes: low flow and moderate flow. Ambient water quality and stream measurements were intended to be used to estimate boundary conditions and for model calibration to provide a base of comparison to observed conditions. Data from reference streams was intended to be used to estimate least disturbed or “background” DO conditions for the Bootheel region.

The Buffalo Ditch Q2K model divides the modeled segment into five reaches that are each divided into ten, equally spaced, elements for iterative calculations. Each of the six sample sites, including the Kennett WWTP, dictate a reach boundary location. However, water quality data for the WWTP discharge is entered as a point source inflow and no transect or water quality data were collected at BU-3. There are no specific withdrawals from the segment and the WWTP is the only point source inflow during low flow conditions. The model was set up and calibrated using stream and water quality data from the May 2008 sampling event when the stream was at moderate flow conditions.

According to the Buffalo Ditch TMDL, the water balance for each reach was calculated using model estimated flows at each sample site and WWTP discharge (BU-3) so that diffuse inflows for each reach are the difference between inflow and outflow. Diurnal DO data sampled at BU-4 was used to calibrate the model. Kinetic rates were adjusted so water chemistry parameters, especially BOD decay downstream of the WWTP, were reasonably simulated. Critical condition adjustments were made to the model, including changing hourly air temperatures and dew point temperatures to match data from the Cardwell Weather Station to a representative day in August 2008. Headwater stream temperature was increased from the BU-1 field measured 21.74 °C to 24.3 °C. Finally, discharge from the WWTP was increased to the design flow of 2.17 cubic feet per second (cfs) or 1.4 million gallons per day (MGD).

The Q2K model identified BOD reductions needed for the WWTP by iteratively running the calibrated, critical condition model at reduced BOD and nutrient concentrations until the DO minimum criterion was met. In the final model, point source and nonpoint source nutrient inputs were set to the ecological drainage unit (EDU) reference values for chl-a (8 µg/L), TN (0.82 mg/L), and TP (0.125 mg/L). The final BOD wasteload allocation for the WWTP was allocated at 5.0 mg/L.

3.3 Technical Issues Identified in the QUAL2K Model

A review of the Buffalo Ditch Q2K model set up and calibration identified technical issues that create uncertainty regarding the accuracy of model predictions of water quality standards attainment. These technical issues include headwater flows and water quality data that are not representative of critical low flow conditions, stream transect inputs that result in flawed hydraulic geometry relations, and an inappropriate formula is used to predict reaeration rates along the segment. Additionally, SOD rates prescribed in the model are not supported by data or literature for modified, productive streams in the Bootheel region. These technical issues taken individually or collectively result in great uncertainty of the model results predicted by Tetra Tech. As a result, the Department questions the ability of the iterative calculations used by the

model to accurately predict changes in water chemistry and physical parameters. Due to this uncertainty, the Department's confidence in the model to predict water quality improvement is diminished. For the following technical reasons, the Department believes the TMDL model and results are inaccurate and should be withdrawn.

3.3.1 Low Flow Conditions

When addressing DO impairments, TMDLs are established at critical low flow conditions when aquatic communities are most vulnerable and threatened by low DO. According to the Buffalo Ditch TMDL and QAPP, summer low flow critical conditions were targeted to minimize inflow from nonpoint (diffuse) sources. Because discharge from the Kennett facility dominates stream flows under low flow conditions, the assumption is that diffuse inflows along the length of the segment should be minimal. Under these conditions, all available loading for nutrients and sediment are allocated to non-stormwater driven point source dischargers and the load allocation assigned to nonpoint sources for all targeted pollutants is zero (Table 1).

The Q2K User Manual (Chapra et al, 2008) calculates steady-state flows (water balance) for each element using a simple mass balance equation (Eq.1; Figure 4).

$$Q_i = Q_{i-1} + Q_{in,i} - Q_{out,i} \quad (\text{Eq. 1})$$

where Q_i = outflow from element i into the downstream element $i + 1$ [m^3/d], Q_{i-1} = inflow from the upstream element $i - 1$ [m^3/d], $Q_{in,i}$ is the total inflow into the element from point and nonpoint sources [m^3/d], and $Q_{out,i}$ is the total outflow from the element due to point and nonpoint withdrawals [m^3/d]. Thus, the outflow at the downstream boundary is simply the difference between boundary inflow and source gains minus losses occurring within the element.

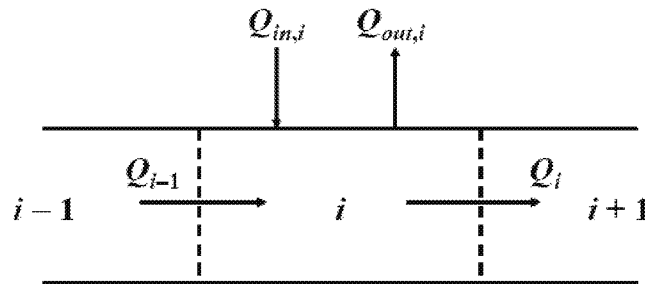


Figure 4. Element flow balance

The designated flow for the headwater boundary starts the series of mass balance equations. The Q2K model used flow measured during the May 2008 sampling event when Buffalo Ditch was

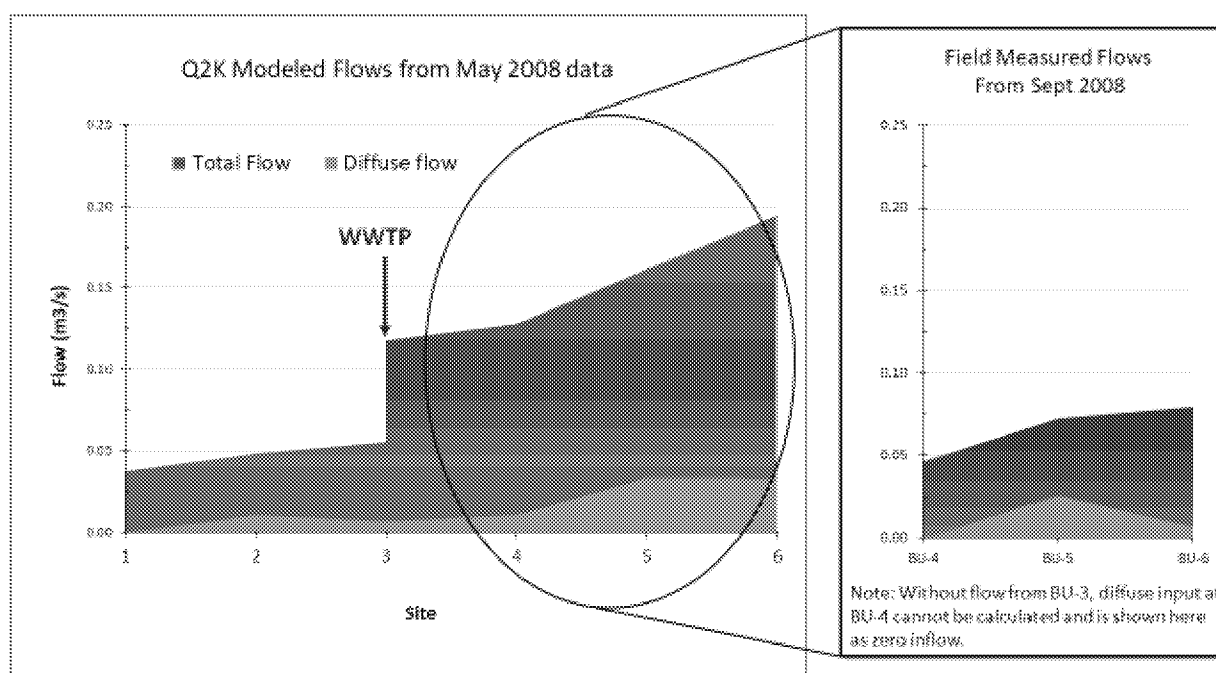


Figure 5. Comparison of total and diffuse flows between model predicted flows using May 2008 field data and the September 2008 field measured flows. Diffuse flow is calculated as the difference between flow at the upstream and downstream boundary for each reach.

experiencing moderate flow conditions. Upstream flow entering the modeled segment was at 0.0375 cubic meter per second (cms) or 1.3 cfs (Table 2). However, stream measurements collected during the September 2008 sampling event indicate lower flows were occurring at that time (Figure 5). The Buffalo Ditch TMDL reports the average flow for the entire segment measured on May 21, 2008, was 3.2 cfs (0.09 cms) and average flow during the September 5, 2008, sampling event was 1.8 cfs (0.05 cms). Also, the average flow reported for the September sampling excludes site BU-2, which had no flowing water at that time.

Because the Q2K model used moderate flow measurements and associated water quality data from May 2008, the BOD wasteload allocation for the Kennett WWTP was not established under critical low flow conditions. Air temperature, dew point temperature, wind speed, cloud cover, and shading are additional factors used in the model for calculating the heat balance of the system and subsequent changes in water temperature, which controls DO saturation potentials. The climate factors used in the final model were adjusted to meet critical conditions by using August 2008 weather data from a nearby climate station; however, these changes are not enough for simulating critical conditions. Hydrogeometric estimations are discussed further in the following section, but for this point, using moderate flow measurements leads to incorrect estimations including water quality, volume of water in each element, travel time along the segment, and longitudinal dispersion. Finally, the model was calibrated to match diel data measured at BU-4 in May 2008. While DO and temperature fluxes may correlate with the flows and water quality at that time, it cannot be assumed to simulate the same trends with lower flows and warmer water temperatures experienced during the summer.

The Buffalo Ditch TMDL highlights the relationship between effluent and downstream nutrient concentrations during both sampling events. The significant decrease in effluent nitrate + nitrite concentrations during the September 2008 sampling event compared to the May data also indicates a seasonal relationship exists. Given the differences in effluent nutrient concentrations, water quality data, and flows between the two sampling events (Table 2), and the subsequent influence on modeled DO concentrations, data collected during critical low flow conditions would be more appropriate for setting up and calibrating the Q2K model when modeling the impact of the WWTP on water quality.

Table 2. Buffalo Ditch measurements from May and September 2008 sampling events

Site	Dist. x(km)	Flow m ³ /s		Depth m		Velocity m/s		Top Width m	
		May	Sept	May	Sept	May	Sept	May	Sept
BU-1	10.1389	0.04	0.01	0.49	0.11	0.001	0.012	8.5	5.18
BU-2	8.3700	0.02	no flow	0.13	---	0.296	---	0.8	---
BU-4	5.3108	0.10	0.047	0.39	0.11	0.041	0.161	6.6	2.74
BU-5	3.0578	0.13	0.072	0.28	0.20	0.082	0.076	5.8	4.88
BU-6	0.0000	0.17	0.079	0.33	0.13	0.072	0.173	7.3	3.66

3.3.2 Hydraulic Geometry Functions

The Q2K model uses the flow measured from each sampling location in power equations that relate mean stream velocity and depth to flow in order to create discharge coefficients.

$$H = \alpha Q^\beta \quad (\text{Eq. 2})$$

$$U = aQ^b \quad (\text{Eq. 3})$$

where a, b, α and β are empirical coefficients generated from velocity-discharge and depth-discharge rating curves. The flow values and discharge coefficients are used to generate depth (Eq.2) and velocity (Eq.3) estimates for each element, which are then used to determine cross-sectional area and width. The surface area and volume of each element are calculated from the estimated cross-sectional areas and widths.

Because the flow, depth, and velocity parameters are interrelated and the coefficients are not completely independent, the Q2K User Manual recommends that the sum of β and b must be less than or equal to 1. If not, the estimated width will decrease with increasing flow.

The hydraulic geometry functions for Buffalo Ditch calculated from the May 2008 field measurements, and excluding BU-2 data, yields values for β (-0.3318) and b (1.4988) that sum

1.167 (Figure 6). The hydraulic summary output of the model confirms a decreased estimation for width along the entire modeled segment (Table 3) and indicates a possible error in the ability of the model to iteratively estimate depth and velocity along the segment.

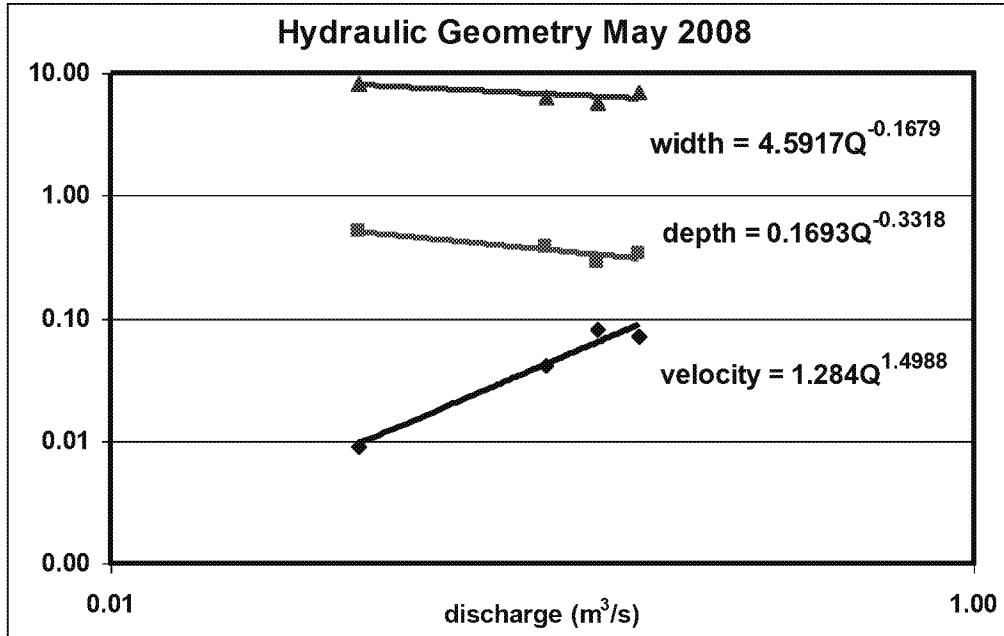


Figure 6. Power equations of hydraulic geometry for Buffalo Ditch, May 2008

Table 3. Field data and model output for hydraulic parameters

Site	Dist. x(km)	Q-data m^3/s		Depth (H) m		Velocity (U) m/s		Top Width (B) m		Cross-sectional Area (A_c) m^2	
		Field	Model	Field	Model	Field	Model	Field	Model	Field	Model
BU-1	10.14	0.037	0.038	0.504	0.503	0.009	0.009	8.53	7.96	4.14	4.01
BU-4	5.31	0.102	0.131	0.385	0.332	0.041	0.061	6.55	6.46	2.47	2.14
BU-5	3.06	0.135	0.164	0.283	0.308	0.082	0.086	5.79	6.22	1.64	1.92
BU-6	0.00	0.167	0.194	0.334	0.334	0.072	0.110	7.32	6.05	2.34	1.77
BU-2*	8.37	0.025	0.049	0.133	0.461	0.305	0.014	0.823	7.610	0.08	3.51

*Site field data not included in power equations

Currently, the Q2K model over-predicts flow, depth, width, and cross-sectional area and under-predicts velocity for site BU-2 (Table 3). While water quality data from BU-2 was used in the model for calibration, transect data from the site was omitted from the hydraulic inputs. As a

result, the estimated flow at BU-2 is double the actual amount measured in the field. Over estimating flow and other interrelated parameters will lead to incorrect rates and concentrations estimated by the model when the WWTP's effluent is added to the model.

The omission of transect information from BU-2 creates additional uncertainty and error in the results of the power equations. The error in the sum of the discharge exponents in the power equations and the over estimation of flow for site BU-2 suggest that a different set-up for this reach may be needed in the model. Given the Kennett WWTP discharge contributes continuous flow during critical conditions, one alternative might be to partition the discharge reach into multiple segments, above and below the outfall, to better refine the stream parameters.

Although stream slope in this water body is an insignificant contributor to stream power, the increase in discharge from the facility should result in different erosional and transport capacity for some distance below the outfall compared to above. Also, the difference in hydraulic properties at BU-2 when compared to BU-1 and BU-4 and the fact that during the September sampling event there was flow at BU-1 and not BU-2 indicates the reach above the outfall has a different hydrology. Therefore, a second alternative might be to combine the first and second reaches into a separate segment in the model. Combining these two reaches would allow for creation of a separate rating curve for the new segment and provide for more accurate loading estimates at the point where the WWTP discharge enters the waterway.

Lastly, stream measurements are recommended to be conducted at BU-3, just above the WWTP outfall, so that the water balance and power equations can be further refined for this water body segment.

3.3.3 Reaeration Rates

The Q2K model simulates stream reaeration as a mass transfer process and ultimately uses it to calculate DO (o) for each element. The model calculates the direction of the net transfer of oxygen (S_o) whether the water is undersaturated from fast carbonaceous BOD oxidation ($CBOD_{fast}$), nitrification, and plant respiration or oversaturated during plant photosynthesis. Oxygen reaeration ($OxReaer$) concentration is added to the final equation (Eq.4).

$$S_o = (\text{oxygen added from phytoplankton, bottom algae, and aquatic vegetation photosynthesis}) \\ - (\text{oxygen used during } CBOD_{fast}, \text{ nitrification, and phytoplankton/bottom algae/aquatic} \\ \text{vegetation respiration}) + OxReaer \quad (\text{Eq. 4})$$

The $OxReaer$ concentration is calculated using the DO saturation potential ($o_s(T, elev)$) [mgO_2/L] and the actual concentration of DO. The DO saturation potential depends on stream temperature (T) and elevation ($elev$) above sea level. Q2K retrieves the temperature and elevation data from the headwater reach inputs.

The difference between DO saturation potential and actual DO values indicates the direction and magnitude of oxygen transfer and is multiplied by the temperature-dependent reaeration coefficient ($K_a(T)$ [d^{-1}]) to find the $OxReaer$ concentration (Eq.5)

$$\text{OxReacr} = k_a(T)(o_s(T, \text{elev}) - o) \quad (\text{Eq. 5})$$

The reaeration coefficient at 20 °C ($k_a(20)$) is calculated from the sum of the reaeration rate at 20 °C computed using the river's hydraulic characteristics ($k_{ah}(20)$) [d^{-1}] and the reaeration mass-transfer coefficient using wind velocity and mean depth ($k_{Lw}(20)/H$) (Eq.6).

$$k_a(20) = k_{ah}(20) + k_{Lw}(20)/H \quad (\text{Eq. 6})$$

Reaeration in the Buffalo Ditch Q2K model was set up as an internal process only, without mixing from wind at the air-water interface, and no reaeration rate was prescribed for any of the reaches; therefore, the reaeration coefficient at 20 °C is equal to the reaeration rate at 20 °C.

The Q2K User Manual specifies if reaeration is not prescribed and the “Internal” option is chosen in the Rates worksheet, then the model will internally calculate reaeration. As a default, the model chooses between the Owens-Gibbs formula, the O'Connor-Dobbins formula, and the Churchill formula, depending on segment depth. The Owens-Gibbs equation was used for the Buffalo Ditch model. However, biotic and abiotic processes in Buffalo Ditch are largely controlled by low slope, low flows, and long travel times. The Tsivoglou-Neal formula more appropriately considers these hydraulic properties and would be a better fit for Buffalo Ditch (Tsivoglou-Neal, 1976).

Tsivoglou and Neal (1976) conducted a comprehensive review of studies on 24 different streams, which measured reaeration capacity and associated hydraulic properties. The water bodies studied varied widely in temperature, BOD, flow, and hydraulic features. The review by Tsivoglou and Neal summarizes 605 individual field measurements of reaeration rates as a function of various hydraulic properties. The meta-analysis included the predictive formulas of Owens-Gibbs, O'Connor-Dobbins, and Churchill that are included in the Q2K model. Using standard statistical procedures, Tsivoglou and Neal tested the adequacy of each reaeration formula by comparing predictive values with observed aeration rates from tracer studies, which are considered to produce the most accurate results of stream reaeration coefficients for each flow condition (USEPA, 1985).

Overall, Tsivoglou and Neal (1976) conclude there is no relationship between specific reaeration capacity of a water body and depth. Rather, the reaeration capacity is a function of time of flow and slope. Slope, especially, is a good indicator of turbulent mixing. The Tsivoglou-Neal formula offers two versions of the equation, depending on water body flow, and is a reaeration equation option in the Q2K model. A comparison of reaeration rates calculated for each element by the Owens-Gibbs formula with the Tsivoglou-Neal formula is presented in Figure 7 and the data are provided in Appendix C.

The difference between reaeration rates at the headwater boundary is 0.68, where Owens-Gibbs predicts a rate of 0.83 and Tsivoglou-Neal predicts a rate of 0.15. After applying the formula using the model estimated slope and velocity for each element, the difference between the predicted rates at the end of the segment is greatly amplified to 11.15, where Owens-Gibbs and Tsivoglou-Neal predicts a rate of 11.83 and 0.69, respectively. This difference in reaeration rate

is considerable in that the TMDL Q2K model may be making a significant overprediction of water body's ability to attain the applicable DO minimum concentration.

Furthermore, the impact of velocity, which is used in both the Owens-Gibbs and Tsivoglou-Neal reaeration formulas, on net DO concentrations underscores the importance of setting up the water quality model in a suitable manner so the hydraulic rating curves appropriately predict velocity and depth along the segment.

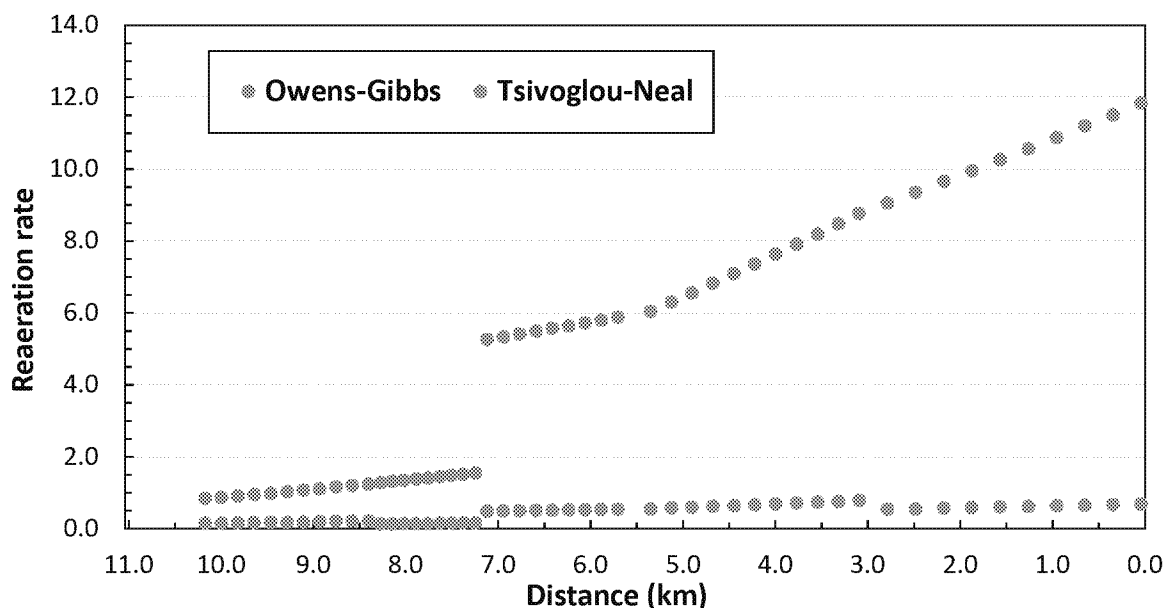


Figure 7. Reaeration rates predicted by Owens-Gibbs and Tsivoglou-Neal formulas

3.3.4 Additional model discrepancies

As noted previously, water quality model set up is critical because headwater inputs begin the iterative equations that estimate nutrient loading and changes in DO along the segment. The Buffalo Ditch Q2K model was set up using data from the May 2008 sampling event. A review of the data found several questionable values. A DO concentration of 6.53 mgO₂/L was entered as the headwater boundary condition; however, this is the concentration entered into the model for BU-2. The field measured DO concentration for BU-1 was 5.23 mgO₂/L; the field measured DO concentration for BU-2 was 8.64 mgO₂/L. Also, the QAPP outlines that the reference stream (BU-ref) was chosen based on minimal anthropogenic impact and that data collected from this site was designed to be used to estimate “background” DO conditions; however, it is not evident how DO values from BU-ref were used in the model. Additionally, it is unclear how a headwater reach water temperature of 24.3 °C was chosen to represent water temperature during a critical condition. Without documentation of these values, the accuracy of the model run can be put into question. Additionally, the remaining headwater water quality data are identical to water quality data from BU-1 except for the pH value, which does not match field data for BU-1 or the reference site (BU-Ref).

As shown above, DO saturation potential is a function of temperature and a key parameter for predicting DO concentrations along a segment. Valid water temperature and DO concentrations are important for setting up the model. Oxygen reaeration rates used to predict DO are calculated at 20 °C and extrapolated to the headwater boundary temperature using a multiplier. The value of the multiplier depends on the difference between the two temperatures and these two values must be as accurate and reflective of ambient conditions as possible.

Input errors were also noticed for reach water quality data. While most of the field and lab water quality data was used, the pH and conductivity values for each site in the model do not match field measurements. Additionally, there is a data input error for BU-4 where the nitrate nitrogen value should be 3900 µg/L, not 3100 µg/L. Without documentation to justify deviating from field measurements, omissions and errors such as these introduce greater uncertainty and error into the model setup and final results used in the TMDL.

3.3.5 Sediment Oxygen Demand Rates

Organic materials (OM) are considered oxygen-demanding substrate in surface waters and derive from both allochthonous sources (e.g. OM from eroded soils, vegetative materials from terrestrial vegetation, and wastewater particulates) and autochthonous sources (e.g. phytoplankton, algae, and aquatic vegetation). OM can be incorporated in sediment pore space and settle onto bottom sediment surfaces. Nutrients from OM mineralization and oxidation, coupled with nutrients from discharged effluent and agricultural runoff, support a cycle of increased primary and secondary production that adds more oxygen demanding substances to the system. Low stream flows and low velocity water decreases the travel time of nutrients moving downstream, resulting in a complete nutrient turnover cycle within a short distance. Streams with short uptake lengths are more sensitive to eutrophication (Nijboer and Verdonchot, 2004).

SOD is the oxygen required to decompose sediment OM and can be a significant fraction of the total oxygen demand in small, productive streams. According to EPA (1985), the major factors influencing SOD are makeup of biological community, organic and physical characteristics of the sediment, water chemistry, water temperature, available oxygen at the sediment-water interface, and velocity of water above the sediment. In low oxygen environments, carbon is mineralized to gaseous methane and nitrogen mineralized to ammonium, creating an oxygen demand in order to oxidize these compounds to carbon dioxide, nitrite, and nitrate.

In the Buffalo Ditch watershed, point and nonpoint sources of OM and mineral nutrients contribute both directly and indirectly to the total SOD of the system. As noted previously, agriculture is the dominant land use in the Buffalo Ditch watershed with crops often growing within the stream riparian zone up to the edge of the streambank. Mineral-associated OM, or soil organic matter, from surface and streambank erosion is a potential source of sediment OM in these instances. The perennial vegetation along the water body also adds OM directly and indirectly (as dissolved organic materials from surface decomposition) to the system. Organic particulates from the Kennett WWTP either remain suspended in the water column or settle onto the bottom sediment. Lastly, the abundant phytoplankton and algae present in Buffalo Ditch that is supported by high nutrient availability continuously supplies detritus to the bottom sediment layer.

The Q2K model computes oxygen and nutrient sediment-water fluxes based on the downward flux of particulate organic matter (POM), e.g., phytoplankton and detritus, from the water column. Broadly, the model computes SOD by estimating sediment-water fluxes of carbon, nitrogen, and phosphorus from the concentration of POM from the water column. However, in addition to the modeled SOD from the downward flux of POM, the model-generated SOD may be insufficient due to the presence of already deposited OM. In this case, an additional supplementary SOD value can be prescribed to compute the total SOD. Figure 8 gives the range and average SOD values of several substrates that are commonly used in water quality models.

In the absence of site-specific SOD measurements, Chapra (1997) outlines that SOD values can be estimated by adjusting the SOD rate until the model predicted DO concentrations match observed concentrations. While this method was commonly used in the early years of water quality modeling, the assumptions that accompany this calibration technique have flaws. The most critical assumption is that all other model parameters, such as reaeration rates and deoxygenation rates, are known with a great degree of confidence.

Bottom Type and Location	Uptake ($\text{g O}_2/\text{m}^2\text{-day}$) @ 20°C	
	Range	Average
<u>Sphaerotilus</u> - (10 gm dry wt/m ²)	-	7
Municipal Sewage Sludge-Outfall Vicinity	2-10.0	4
Municipal Sewage Sludge-"Aged" Downstream of Outfall	1-2	1.5
Estuarine mud	1-2	1.5
Sandy bottom	0.2-1.0	0.5
Mineral soils	0.05-0.1	0.07

Figure 8. Average SOD Rates from EPA's Rates and Kinetics Manual (USEPA, 1985)

The Buffalo Ditch Q2K model calibration tested several SOD values (4.0, 10.0, 8.0, and 5.0 $\text{gO}_2/\text{m}^2/\text{d}$). The final values used were a SOD of 0.75 grams of oxygen per square meter per day ($\text{gO}_2/\text{m}^2/\text{d}$) prescribed for reaches 1 and 2, which are above the WWTP outfall, and 3.0 $\text{gO}_2/\text{m}^2/\text{d}$ prescribed for reaches 3, 4, and 5. The model estimated SOD values for the entire segment ranged from 3.2 - 6.6 $\text{gO}_2/\text{m}^2/\text{d}$. The final TMDL model scenario, which predicted the Kennett WWTP BOD limit, reduced the prescribed background SOD to 0.1 $\text{gO}_2/\text{m}^2/\text{d}$ for all reaches. This SOD rate is significantly below the range used for the model calibration and not reflective of the type of stream substrate conditions found in Buffalo Ditch (i.e., muddy rather than mineral solids, see Figure 8).

Even without significant inflow from diffuse sources BOD may be introduced along the water body by interactions with dissolved OM in pore water of bottom sediment. Introduction of this type of BOD is even more plausible when considering the inherent characteristic of alluvial soils in the area to have enriched organic content. Additionally, low flows and low stream velocity would not readily flush POM downstream, allowing sediment and POM accumulate on the stream bottom. The calibrated, prescribed SOD values in the model should adequately characterize anticipated background SOD along the entire segment. Since the model computes a total SOD using the prescribed SOD and the SOD estimated from settled POM, the prescribed SOD values should not be different in the final model run from the calibrated model. The manipulation of the SOD rate in the model outside the boundaries of calibrated and real-world conditions is not appropriate or representative of good modeling practice.

3.4 Technical Issues with Development of Load Duration Curves and Synthetic Flow Record

For the Buffalo Ditch TMDL, an ecoregion nutrient and TSS load duration curve approach was used. Load duration curves were used to calculate the loading capacity of Buffalo Ditch for TN, TP, and TSS. These load duration curves are presented in Figures 6 through 8 of the TMDL document and were used to derive loading allocations to nonpoint sources and the Kennett MS4. Due to the influence of precipitation on pollutant loading from these sources, the calculated wasteload and load allocations for these sources vary with flow as well as any loading reductions necessary for attaining water quality standards.

In general, EPA recommends this specific load duration curve approach using ecoregional criteria be used only for streams having watersheds greater than 80 square miles. For watersheds of a smaller size, such as the 56 square mile Buffalo Ditch watershed, this method produces a less accurate estimate of the percent of time a load may be expected. As a result, the developed load duration curve overestimates the time in which loads will be seen at the lower percentile and underestimates the load duration on the opposite end of the curve. Due to the size of the Buffalo Ditch watershed, a more appropriate reference approach is needed to more accurately estimate load durations in order to better estimate allowable pollutant loading and guide implementation activities in the watershed over a range of flows.

In addition to applicability of the approach due to the size of the watershed, issues associated with development of a synthetic flow record for Buffalo Ditch have also been observed. In order to develop a load duration curve, a long record of average daily flow data from a gage (or multiple gages) that is representative of the impaired reach is needed. The flow record should be of sufficient length to be able to calculate percentiles of flow. If a flow record for an impaired stream is not available, then a synthetic flow record can be developed. For the Buffalo Ditch TMDL, a synthetic flow record was created from data collected from USGS stream gages in Missouri, Arkansas, Illinois, and Kentucky (Table 4 and Figure 9).

Table 4. Stream gages used to develop a synthetic flow record for Buffalo Ditch

USGS Gage	Drainage Area (mi ²)	8-Digit HUC
07021000 Castor River at Zalma, MO	423	07140107
03612000 Cache River at Forman, IL	244	05140206
07043500 Little River Ditch No. 1 near Morehouse, MO	450	08020204
07042500 Little River Ditch 251 near Lilbourn, MO	235	08020204
07025400 North Fork Obion River near Martin, Tenn (ce)	372	08010203
07040100 St. Francis River at St. Francis, AR*	1,770	08020203
07039500 St. Francis River at Wappapello, MO*	1,311	08020203

*Note: Data from the two St. Francis River gages were used to estimate a flow record for a more representative tailwater watershed with a watershed area of 459 square miles.

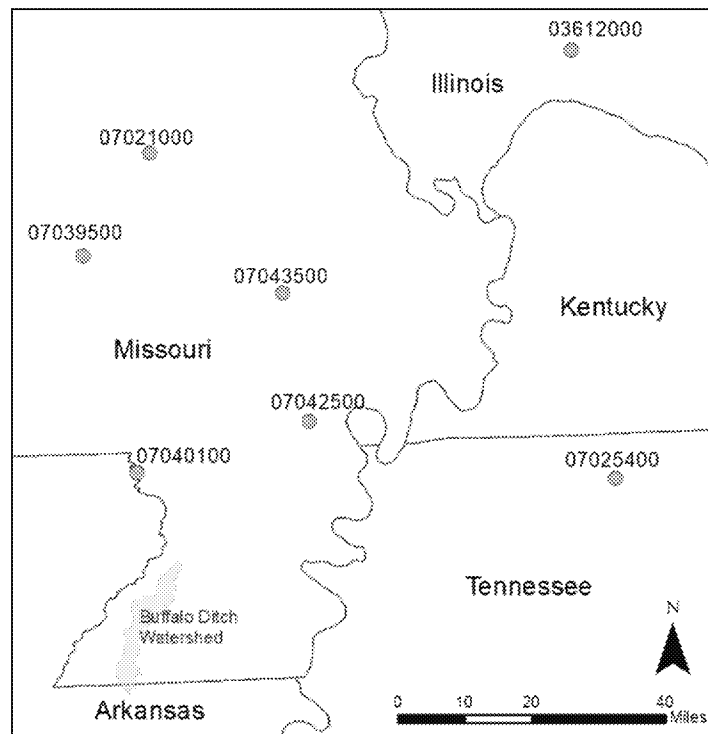


Figure 9. Location of stream gages used to develop synthetic flow for Buffalo Ditch

For each gage flow record used to develop the synthetic flow, Nash-Sutcliffe statistics are calculated to determine if the relationship is valid for each record. The Nash-Sutcliffe statistic evaluates the efficiency of a predicted (modeled) flow dataset (Nash and Sutcliffe 1970). An efficiency of 1 (100 percent) describes a perfect match, while values less than zero indicate a poor fit of modeled and observed datasets (USGS 2010). This relationship must be valid in order to use the synthetic flow methodology. Table 5 presents Nash-Sutcliffe statistics for gage data

used for the development of a synthetic flow record for Buffalo Ditch. Although all gages showed efficiencies greater than zero, datasets from two gages, Castor River at Zalma and Little River Ditch 251 near Lilbourn, showed lower statistical fits of only 30 percent. According to the USGS, model estimates are to be considered satisfactory if Nash-Sutcliffe statistics are greater than 50 percent (USGS 2013). The statistics provided for the Castor River and Little River Ditch 251 indicate that these gages were inappropriate for use in developing a synthetic flow for Buffalo Ditch. Average Nash-Sutcliffe statistics for all gages used in developing the Buffalo Ditch TMDL yields a value of 65 percent, but excluding the two gages having a low statistical fit results in a much higher average Nash-Sutcliffe statistic of 82 percent. Therefore, a more representative estimate of flow in Buffalo Ditch may have been developed had the Castor River and Little River Ditch 251 gages not been included in the synthetic flow dataset or if more representative gages had been used instead.

Table 5. Nash-Sutcliffe statistics for gages used to develop synthetic flow for Buffalo Ditch

Stream Gage	Nash-Sutcliffe Statistic
07021000 Castor River at Zalma, MO	31%
03612000 Cache River at Forman, IL	69%
07043500 Little River Ditch No. 1 near Morehouse, MO	71%
07042500 Little River Ditch 251 near Lilbourn, MO	30%
07025400 North Fork Obion River near Martin, Tenn (ce)	89%
St. Francis gages tailwater corrected flow	97%

In addition to issues associated with the statistical efficiency of the modeled synthetic flow, other factors associated with conditions influencing the flow at individual gages are also of concern. To develop a synthetic flow record for Buffalo Ditch, an average of the log discharge per square mile was calculated from USGS gage data. Due to a lack of available gage data within the same EDU as Buffalo Ditch, gages from neighboring EDUs were used. Gages within the same EDU are preferred, because EDUs are groups of watersheds that have similar biota, geography, and climate characteristics (USGS 2009). However, other gages may be appropriate if their watersheds have similar size, geology, climate, land use, and stream characteristics. For the Buffalo Ditch TMDL, gaged streams selected to develop a synthetic flow record lack key characteristics that are representative of the conditions influencing flow in Buffalo Ditch. Primary physical differences influencing flow that are not representative of Buffalo Ditch include slope and watershed size.

Stream flow is the volume of water that moves over a designated point over a fixed period of time and is therefore a function of water volume and velocity (USEPA 2012). One factor influencing stream volume is the amount of land area available to contribute water directly to a stream. For Buffalo Ditch, the watershed area draining to the stream is approximately 56 square miles. As can be seen in Table 4, drainage areas for gaged streams used to develop the synthetic flow are considerably larger. The average drainage area for all gages used to develop the synthetic flow is approximately 364 square miles, which is more than 6.5 times greater than the Buffalo Ditch watershed. The area draining the Little River Ditch 251 gage is the smallest of the

gages used and is still four times greater than the area contributing water to Buffalo Ditch. Another factor influencing the volume of water and stream velocities in Buffalo Ditch is slope. As previously discussed, Buffalo Ditch lies within the relatively flat Missouri Bootheel and is characterized as having a low stream gradient that contributes to lower flows and velocities (Section 2.2). In addition to watershed size, several gages used to derive a synthetic flow also have slopes that are unrepresentative of conditions in Buffalo Ditch. Table 6 shows the percent of slope and elevation change along the gaged streams. These differences in slope, particularly in regards to the Castor River and streams located outside Missouri, in combination with the substantial difference in watershed size likely result in overestimates of flow for Buffalo Ditch and inaccurate pollutant loading allocations to stormwater dependent sources. These overestimates limit the appropriateness of this approach for calculating loading capacities for Buffalo Ditch and assigning allocations to nonpoint sources and the Kennett MS4 as a function of stream flow.

Table 6. Estimates of slope for gaged streams used to develop the Buffalo Ditch synthetic flow

USGS Gage	Channel Length (mi)	Elevation Change (ft)	Stream Slope (%)	Degree Slope
07021000 Castor River at Zalma, MO	62.6	547.8	0.16576	0.095
03612000 Cache River at Forman, IL	43.3	129.7	0.05665	0.032
07043500 Little River Ditch No. 1 near Morehouse, MO	30.0	31.9	0.02019	0.012
07042500 Little River Ditch 251 near Lilbourn, MO	35.0	32.6	0.01765	0.010
07025400 North Fork Obion River near Martin, TN	37.9	159.5	0.07955	0.046
St. Francis gages tailwater corrected flow	78.7	43.9	0.01058	0.006

(Source: USGS StreamStats. <https://water.usgs.gov/osw/streamstats/>)

3.5 TMDL Review Conclusions

The Department reviewed the Buffalo Ditch DO TMDL, its associated water quality models, and available empirical data, and has determined that the wasteload and load allocation targets established in the Buffalo Ditch TMDL will not result in attainment of the applicable DO criterion of 5.0 mg/L. While a minimum DO criterion of 5.0 mg/L may be inappropriate for this region and will be investigated further by the Department for potential site-specific or regional criteria, the models used in the Buffalo Ditch TMDL were fundamentally unrepresentative of conditions found in Buffalo Ditch. The Q2K model was set up using incorrect headwater data, flows not from low flow conditions, and an incorrect reaeration formula; therefore, critical conditions were not truly modeled. In using moderate stream flow measurements, the hydraulic rating curve incorrectly estimates hydrogeometric parameters. Also, prescribed SOD values do

not reflect the background condition of the water body. Lastly, issues identified with the development of the TMDL load duration curves result in inaccurate estimates of pollutant loading and needed reductions from stormwater driven sources in order to attain and maintain water quality standards.

Due to the issues identified in the TMDL models, the Department is proposing to withdraw the Buffalo Ditch TMDL and re-categorize the Buffalo Ditch DO impairment as Category 5 for inclusion on the Missouri 303(d) list of impaired waters. Waters included on the 303(d) list will be prioritized and scheduled for TMDL development as required in 40 CFR §130.7(b)(4) and the inaccuracies and errors noted in this withdrawal will be addressed at that time. Implementation actions and other planning efforts in the Buffalo Ditch watershed that are more immediately beneficial or practicable for achieving water quality standards than a revised TMDL may result in further subcategorized of this impairment as Category 5-alt. Category 5-alt waters remain on the 303(d) list, but are considered low priority for TMDL development.

This TMDL withdrawal was made available for public comment through a 45-day public notice period from October 12 through November 26, 2018. Comments received and the Department's responses to those comments will be maintained on file with the Department and on the Buffalo Ditch TMDL record website at dnr.mo.gov/env/wpp/tmdl/3118-buffalo-ditch-record.htm.

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Appendix A

Anticipated Implementation Actions for Addressing the Buffalo Ditch Low Dissolved Oxygen Impairment

Following withdrawal of the Buffalo Ditch TMDL, the Department will evaluate strategies for developing a new TMDL. TMDL development for Buffalo Ditch will be prioritized and scheduled as required at 40 CFR §130.7(b)(4). Implementation actions and other planning efforts in the Buffalo Ditch watershed that may result in attainment of water quality standards more quickly than can be achieved through the development of a revised TMDL may serve as an alternative to a TMDL. The Buffalo Ditch watershed is a mixed-source watershed, with potential pollutant loading that may contribute to low DO conditions coming from urban runoff into a MS4, agricultural runoff from cropland, and treated effluent from the Kennett WWTP.

Urban Runoff

Urban stormwater discharges from the city of Kennett's MS4 are regulated through a general Missouri State Operating Permit for stormwater, permit number MO-R040069. Nutrient loading to receiving waters from urban stormwater may result from lawn fertilizers and pet and yard waste. Increasing water temperature resulting from urban runoff originating from paved areas is an additional stressor that may contribute to low dissolved oxygen conditions. Although stormwater discharges are often untreated, MS4 permit holders must develop, implement, and enforce stormwater management plans to reduce the contamination of stormwater runoff and prohibit illicit discharges. These plans must include measurable goals, be reported on annually, and meet six minimum control measures:

- Public education and outreach;
- Public participation and involvement;
- Illicit discharge detection and elimination;
- Construction site runoff control;
- Post-construction runoff control; and
- Pollution prevention.

Various structural and nonstructural best management practices (BMPs) are available to help reduce nutrient loading from urban runoff sources. Table A1 lists examples of commonly accepted BMPs for reducing nutrient loading in stormwater. Incorporating these practices as part of MS4 permit compliance or voluntarily by private property owners, will aid in addressing the low dissolved oxygen impairment of Buffalo Ditch. Note that this table is meant to provide examples of commonly accepted practices. It is not meant to preclude other practices that may be more appropriate to any particular project or site.

Table A1. Common urban land management practices to reduce nutrient loading

Type of Practice	Practice Mode of Action		
	Avoid	Control	Trap
Bioswale		X	X
Detention basin		X	X
Fertilizer management	X	X	
Enhanced infiltration (soil amendment)	X	X	X
Irrigation management	X	X	
Low impact landscaping	X		
Porous pavement		X	X
Rain garden		X	X
Rain water harvesting	X	X	

Agricultural Runoff

Land use in the Buffalo Ditch watershed is approximately 91 percent cultivated cropland. Lands where chemical fertilizers or animal manure are applied can be sources of mineral and organic nutrient loading to surface waters due to soil erosion and runoff. Such pollutant contributions are diffuse in nature and exempt from Department permit regulations. However, various BMPs may be voluntarily implemented by landowners to reduce nutrient loads originating from cropland in the watershed. Table A2 lists cropland BMPs that are commonly used in Missouri. Landowners looking to implement such practices may be eligible to receive potential funding assistance through Section 319-funded subgrants or through cost-share assistance from the Department's Soil and Water Conservation Program. More information regarding these programs is available by calling 573-751-4932.

Table A2. Common agricultural best management practices to reduce nutrient loading

Type of Practice	Description
Cover crops	Vegetation planted to reduce surface erosion after harvest until the next crop
Nutrient management plans	A plan to manage the amount, placement, and timing of applications of manure fertilizers
Conservation crop rotation	Various crops grown on the same land in a planned rotation, which reduces erosion
Grassed waterways	A grassed strip to convey water and prevent gully formation
Terraces	An earth embankment across the slope of a field to intercept runoff and trap soil
Vegetative Buffers	Permanently vegetated areas that reduce sediment loss
Water retention structures	Structures to control runoff and prevent erosion

Kennett WWTP

Discharges of treated domestic wastewater can also be a source of nutrients that contribute to algae growth as well as a source of organic substances that may increase the BOD of the receiving water body. Pollutant contributions from the Kennett WWTP are regulated by a site-specific Missouri State Operating Permit, permit number MO-0028568. This plant is a three-cell lagoon system with a design flow of 1.4 MGD. Actual flow averages approximately 0.75 MGD.

On June 27, 2018, the Department issued construction permit CP0001944 to the city of Kennett for upgrades and improvements to the existing WWTP. Plant improvements are scheduled to begin in September 2018 and will be completed by June 2019. Planned improvements include a retrofit of the lagoon system to a Moving Bed Bio-Reactor (MBBR) process, which will result in effluent quality with considerably lower BOD, TSS, and ammonia concentrations than currently discharged by the plant. Reductions in these pollutant loads will have a positive effect on water quality in the impaired segment of Buffalo Ditch. The MBBR system will consist of two parallel trains, each with three stages of MBBRs. The MBBRs will be supplied with a media fill percentage of 50 percent, allowing for significant expandability to handle additional future loadings. The system will rely on a stainless steel, medium bubble diffuser system in lieu of fine bubble or plastic coarse bubble diffusers to increase operational reliability and the system will be equipped with 100 percent redundancy by providing two tri-lobe blowers, each with the ability to meet the full oxygen supply requirements. The MBBR system has been designed to handle low temperature conditions by handling a fraction of raw sewage with a fraction of lagoon effluent, to maintain MBBR temperatures above 5 °C. The system has been designed to meet the water quality requirements outlined in the operating permit. Additionally, the planned upgrades will include a tertiary disk filtration system for BOD and TSS reduction, and ultraviolet disinfection. The tertiary filtration system will filter out the biological solids generated in the biological treatment process and maintain TSS and biochemical oxygen levels in effluent safely below the permitted levels. The tertiary filtration system will be supplied with a spare drive assembly to provide additional reliability. The ultraviolet light disinfection system includes 100 percent redundancy and will safely maintain the disinfection requirements over the design conditions.

In addition to these upgrades, the City has been re-lining manholes, installing manhole cover devices, and conducting smoke testing to identify and reduce inflow and infiltration (I&I) issues. Over the past five years, the City has re-lined approximately 40 manholes and installed over 100 manhole “insert” covers to reduce infiltration. Those efforts have been successful in reducing I&I. The City now voluntarily includes evaluation, repair, and rehabilitation of sewer mains, manholes, and pumping stations in each annual budget to make maintenance and care of the system an integrated part of the overall operation. The City anticipates continuing these efforts to further reduce I&I and improve wet weather treatment and conveyance performance.

Adaptive Implementation

Except in cases where activities and schedules are required by legally binding requirements, such as established permit conditions, an adaptive implementation approach that makes progress toward achieving water quality goals while using new data and information to reduce uncertainty and adjust implementation activities will be used. If future data demonstrate that Buffalo Ditch attains applicable water quality criteria, the water body will be removed from the 303(d) list and

re-categorized as either Category 2 or 3, as appropriate. If future data demonstrate that Buffalo Ditch does not attain applicable water quality criteria, the impairment will be addressed with either a new TMDL or other appropriate regulatory mechanisms.

Appendix B

Summary of Data Collection Efforts in the Bootheel Region for Development of the Buffalo Ditch TMDL and Potential Regulatory Alternatives

Given the unique history and existing physical conditions of streams throughout the Bootheel, the currently applicable 5.0 mg/L DO minimum criterion may not be an appropriate regulatory target for the region. The historical wetland draining activities and associated land use changes in the region have created conditions that are known to reduce DO and prevent the existing DO criterion from being widely attained. The TMDL document acknowledges these challenges by stating, “due to issues regarding low DO as a natural background condition, the Department may develop revised DO criteria for Buffalo Ditch and similar streams...” These conclusions are supported by empirical DO data that demonstrate that even high quality reference streams in the region do not attain the existing criterion. Therefore, a site-specific DO criterion for Buffalo Ditch or other regional DO criteria for Bootheel streams may be more appropriate.

Summary of Data Collection

The inability of Buffalo Ditch and other streams in the surrounding region to consistently attain Missouri’s minimum DO criterion of 5.0 mg/L is empirically evident based on data collected by the Department and EPA in 2003 and 2008 prior to the finalization of the TMDL. As part of the Department’s 2003 data collection effort, DO data were collected from the following three locations outside the influence of the Kennett WWTP (Figure B1):

- **Site M1** – Buffalo Ditch approximately 0.9 miles upstream of the Kennett WWTP.
- **Site M6** – Ditch #36 at the County Road 502 bridge crossing. According to the Department’s 2003 Stream Survey Sampling Report, this site was chosen in order to characterize DO and other parameters in a local ditch that was unaffected by WWTP discharges.
- **Site M7** – Ragland Slough at the Highway A bridge crossing. According to the Department’s 2003 Stream Survey Sampling Report, this site was chosen in order to characterize DO and other parameters in a local ditch that was unaffected by WWTP discharges.

As part of EPA’s 2008 data collection effort, DO data were collected from the following three locations outside the influence of the Kennett WWTP (Figure B1):

- **Site BU-1** – Buffalo Ditch 1.9 miles upstream of the Kennett WWTP at Highway 412.
- **Site BU-2** – Buffalo Ditch 0.8 miles upstream of the Kennett WWTP at County Road 508.
- **Site BU-RF** – Unnamed tributary to Main Ditch at County Road 231. According to the TMDL QAPP, the reference stream was chosen for having minimal anthropogenic (human) impact. The QAPP also indicated that data from reference streams were to be used for estimating “background” DO conditions.

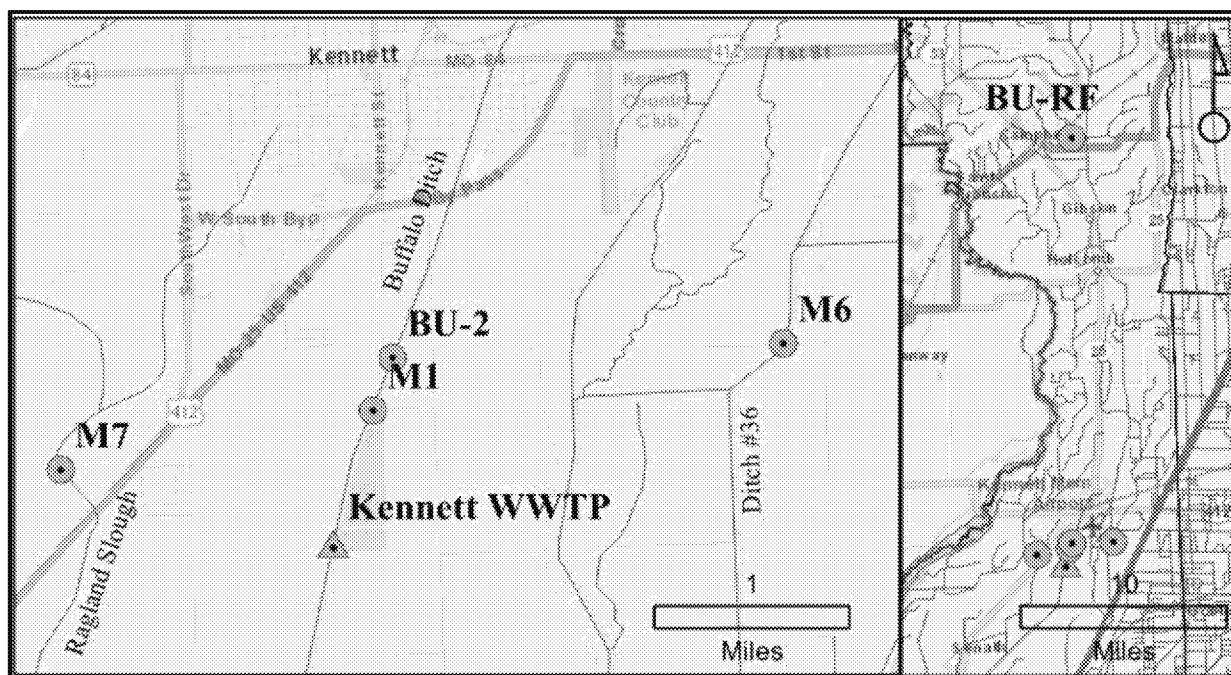


Figure B1. Buffalo Ditch TMDL Upstream and Reference Sites

Minimum DO concentrations measured at these reference and non-reference sites were below the water quality criterion and ranged from approximately 1.0 mg/L to 3.0 mg/L during the 2003 and 2008 stream studies (Figure B2). These results are consistent with data collected from other reference streams in the Bootheel region. For example, approximately 60 percent of the continuous DO data collected in Maple Slough Ditch (Water Body ID 3140), which is a biocriteria reference stream, are below the existing water quality criterion. As a result, Maple Slough Ditch is considered impaired for DO (MoDNR 2016). Collectively, these data suggest that a 5.0 mg/L minimum DO criterion cannot be attained consistently even in high quality, least disturbed Bootheel streams.

Regulatory Alternatives

Federal regulations at 40 CFR 131.11(b)(1)(ii) allow states to adopt water quality criteria that are "...modified to reflect site-specific conditions." In Missouri, site-specific criteria are allowed (10 CSR 20-7.031(5)(S)) when existing criteria are either "under-protective or over-protective of water quality due to natural, non-anthropogenic conditions..." According to federal guidance, aquatic life protection water quality criteria may be considered over- or under-protective if designated uses are supported but naturally occurring pollutant concentrations exceed national criteria published under section 304(a) of the Clean Water Act (USEPA 1997). In such cases, EPA acknowledges (63 FR 36761) that ambient-based criteria can be developed following an evaluation of natural background (reference) conditions. The Department is committed to investigating the potential for developing new DO criteria for Bootheel streams based on the natural background approach.

In some instances, aquatic community data may indicate Bootheel streams do not support existing designated warm-water habitat (WWH) aquatic life uses (10 CSR 20-7.031(1)(C)(1)).

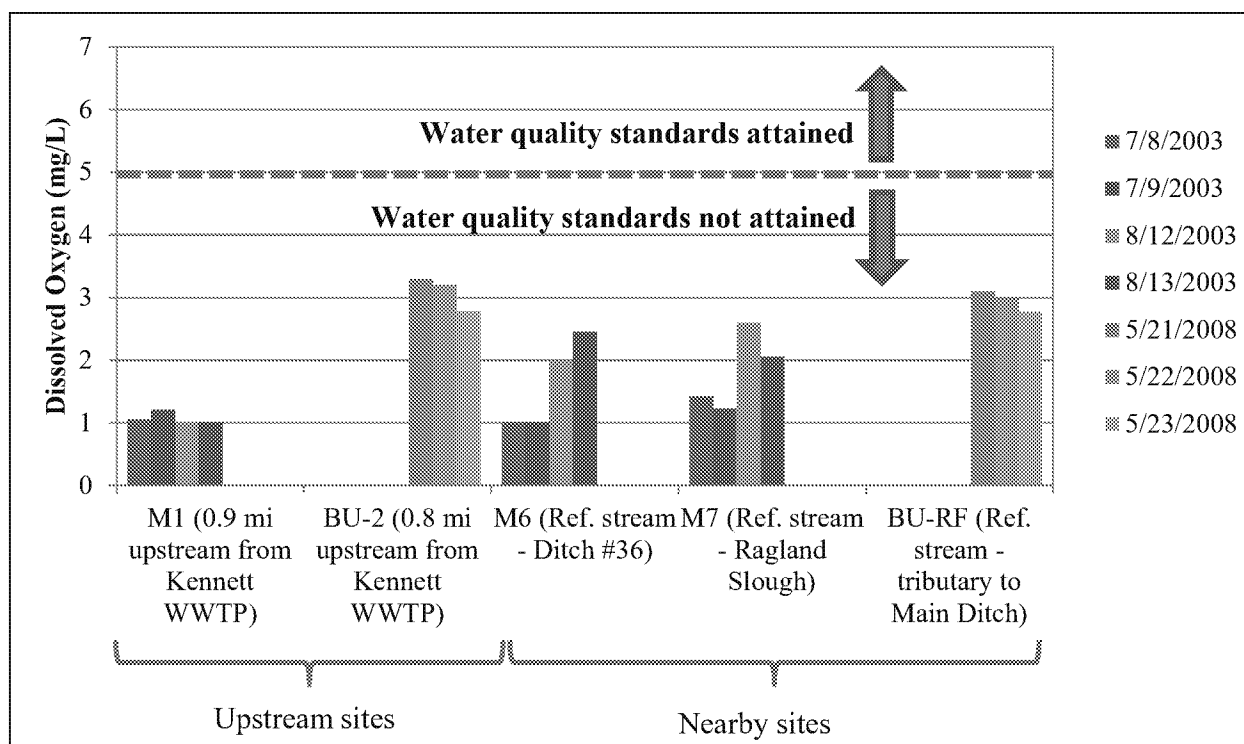


Figure B2. Summary of Measured Minimum DO Concentrations

For these streams, an alternative designated use may be appropriate. State regulations currently include two alternative aquatic life protection use categories that may be applicable to Bootheel streams: modified aquatic habitat (MAH) and limited aquatic habitat (LAH). The two aquatic life protection use categories are not currently differentiated from the WWH category by specific water quality criteria. Rather, the uses are broadly defined by narrative descriptions that characterize a gradient of aquatic community conditions that result from activities that permanently alter water quality or habitat conditions.

Federal regulations (40 CFR 131.10) prevent states from removing or downgrading existing designated uses unless a use attainability analysis (UAA) is completed. A UAA (40 CFR 131.3(g)) is a structured scientific assessment of factors that affect attainment of the use which may include physical, chemical, biological, and economic factors as described in 40 CFR 131.10(g). The 131.10(g) factors are:

1. Naturally occurring pollutant concentrations prevent the attainment of the use; or
2. Natural, ephemeral, intermittent or low flow conditions or water levels prevent the attainment of the use, unless these conditions may be compensated for by the discharge of sufficient volume of effluent discharges without violating State water conservation requirements to enable uses to be met; or

3. Human caused conditions or sources of pollution prevent the attainment of the use and cannot be remedied or would cause more environmental damage to correct than to leave in place; or
4. Dams, diversions or other types of hydrologic modifications preclude the attainment of the use, and it is not feasible to restore the water body to its original condition or to operate such modification in a way that would result in the attainment of the use; or
5. Physical conditions related to the natural features of the water body, such as the lack of a proper substrate, cover, flow, depth, pools, riffles, and the like, unrelated to water quality, preclude attainment of aquatic life protection uses; or
6. Controls more stringent than those required by sections 301(b) and 306 of the Act would result in substantial and widespread economic and social impact.

The Department is currently working to develop draft aquatic life UAA procedures and expects to offer those procedures for public review and comment by the end of 2018. Once finalized, the Department will evaluate the potential for applying the procedures to Buffalo Ditch and other Bootheel streams to establish alternative designated uses and DO criteria for these waters.

References:

MoDNR (Missouri Department of Natural Resources). 2016. 303(d) List of Impaired Waters.
<https://dnr.mo.gov/env/wpp/waterquality/303d/303d.htm>

USEPA (U.S. Environmental Protection Agency). 1997. Establishing Site Specific Aquatic Life Criteria Equal to Natural Background. Washington, D.C.
<https://www.epa.gov/sites/production/files/2014-08/documents/naturalbackground-memo.pdf>

Appendix C

Comparison of Reaeration Rates Estimated by Owens-Gibbs and Tsivoglou-Neal Formulas

The Q2K model offers several reaeration formulas to choose from depending on the hydraulic geometry of the water body and available data. The majority of reaeration formulas listed in the Q2K user manual utilize depth and velocity. If 'Internal' is selected for reaeration formula during model setup, Q2K uses the following decision scheme when choosing the default formula to use, where H is the water body depth:

- If $H < 0.061$ m, use the Owens-Gibbs formula
- If $H > 0.61$ m and $H > 3.45U^{2.5}$, use the O'Connor-Dobbins formula
- Otherwise, use the Churchill formula

The Owens-Gibbs formula (Eq. C-1) was the internal default formula used in the Buffalo Ditch Q2K model. The equation calculates reaeration rate at 20 °C ($K_a(20)$) using velocity (U) and depth (H).

$$K_a(20) = 5.32 (U^{0.67}/H^{1.85}) \quad \text{(Eq. C-1)}$$

However, several other formulas incorporate slope and are chosen based on flow. Equations from USGS (Melching and Flores, 1999) specify use for pool-riffle or channel-controlled water body. Tsivoglou and Neal (1976) provides equations for high ($Q = 0.4247$ to 84.938 cms (15 to 3000 cfs)) and low flow ($Q = 0.0283$ to 0.4247 cms (1 to 15 cfs)) conditions and incorporates slope (S) and travel time into the equation. The Tsivoglou-Neal formula (Eq. C-2) for estimating reaeration rates at low flows is better suited for the low flows and long travel times in Buffalo Ditch during critical conditions.

$$K_a(20) = 31,183US \quad \text{(Eq. C-2)}$$

A comparison of reaeration rates estimated by the Owens-Gibbs and Tsivoglou-Neal formulas shows a significant divergent in rates with each element along the water body. The results shown in Table C-1 highlights the importance in carefully choosing model parameters to best reflect the water body.

Table C-1. Buffalo Ditch hydraulic summary and reaeration rates

Site	Distance km	Flow m ³ /s	Slope	Velocity mps	Depth m	Owens- Gibbs K _{ah} (20)	Tsivoglou- Neal K _{ah} (20)	Difference
BU-1	10.13	0.0375	0.0005	0.009	0.50	0.83	0.15	0.68
	9.95	0.0385	0.0005	0.010	0.50	0.87	0.15	0.71
	9.78	0.0396	0.0005	0.010	0.49	0.91	0.16	0.75
	9.60	0.0407	0.0005	0.011	0.49	0.95	0.16	0.78
	9.42	0.0418	0.0005	0.011	0.49	0.99	0.17	0.81
	9.25	0.0429	0.0005	0.011	0.48	1.03	0.18	0.85
	9.07	0.0439	0.0005	0.012	0.48	1.07	0.19	0.89
	8.89	0.0450	0.0005	0.012	0.47	1.11	0.19	0.92
	8.71	0.0461	0.0005	0.013	0.47	1.16	0.20	0.96
	8.54	0.0472	0.0005	0.013	0.47	1.20	0.21	0.99
	8.36	0.0482	0.0005	0.014	0.46	1.25	0.21	1.03
BU-2	8.23	0.0490	0.0003	0.014	0.46	1.28	0.13	1.15
	8.10	0.0498	0.0003	0.014	0.46	1.31	0.13	1.18
	7.98	0.0505	0.0003	0.015	0.46	1.34	0.14	1.21
	7.85	0.0513	0.0003	0.015	0.45	1.38	0.14	1.24
	7.72	0.0521	0.0003	0.015	0.45	1.41	0.14	1.27
	7.59	0.0529	0.0003	0.016	0.45	1.44	0.15	1.30
	7.46	0.0536	0.0003	0.016	0.45	1.48	0.15	1.33
	7.34	0.0544	0.0003	0.016	0.44	1.51	0.15	1.36
	7.21	0.0552	0.0003	0.017	0.44	1.55	0.16	1.39
	7.08	0.1174	0.0003	0.052	0.34	5.25	0.48	4.77
BU-3	6.90	0.1185	0.0003	0.053	0.34	5.33	0.49	4.84
	6.73	0.1196	0.0003	0.053	0.34	5.41	0.50	4.91
	6.55	0.1206	0.0003	0.054	0.34	5.49	0.50	4.98
	6.37	0.1217	0.0003	0.055	0.34	5.56	0.51	5.05
	6.20	0.1227	0.0003	0.055	0.34	5.64	0.52	5.13
	6.02	0.1238	0.0003	0.056	0.34	5.72	0.52	5.20
	5.84	0.1249	0.0003	0.057	0.34	5.80	0.53	5.27

Buffalo Ditch Total Maximum Daily Load Withdrawal

Site	Distance km	Flow m3/s	Slope	Velocity mps	Depth m	Owens- Gibbs K _{ah} (20)	Tsivoglou- Neal K _{ah} (20)	Difference
	5.66	0.1259	0.0003	0.058	0.34	5.88	0.54	5.34
	5.31	0.1280	0.0003	0.059	0.33	6.04	0.55	5.49
BU-4	5.08	0.1313	0.0003	0.061	0.33	6.30	0.57	5.72
	4.86	0.1347	0.0003	0.064	0.33	6.56	0.59	5.96
	4.63	0.1380	0.0003	0.066	0.33	6.82	0.62	6.20
	4.41	0.1413	0.0003	0.068	0.32	7.09	0.64	6.45
	4.18	0.1446	0.0003	0.071	0.32	7.36	0.66	6.69
	3.95	0.1479	0.0003	0.073	0.32	7.63	0.68	6.95
	3.73	0.1512	0.0003	0.076	0.32	7.91	0.71	7.20
	3.50	0.1545	0.0003	0.078	0.31	8.19	0.73	7.46
	3.28	0.1578	0.0003	0.081	0.31	8.48	0.75	7.72
BU-5	3.05	0.1611	0.0003	0.083	0.31	8.77	0.78	7.99
	2.75	0.1644	0.0002	0.086	0.31	9.06	0.54	8.52
	2.44	0.1677	0.0002	0.088	0.31	9.35	0.55	8.80
	2.14	0.1710	0.0002	0.091	0.30	9.65	0.57	9.08
	1.83	0.1743	0.0002	0.094	0.30	9.95	0.58	9.37
	1.53	0.1775	0.0002	0.096	0.30	10.26	0.60	9.66
	1.22	0.1808	0.0002	0.099	0.30	10.56	0.62	9.95
	0.92	0.1841	0.0002	0.102	0.30	10.88	0.63	10.24
	0.61	0.1874	0.0002	0.104	0.30	11.19	0.65	10.54
	0.31	0.1907	0.0002	0.107	0.29	11.51	0.67	10.84
BU-6	0.00	0.1939	0.0002	0.110	0.29	11.83	0.69	11.15